

RHIC DYNAMIC APERTURE AND BEAM LIFETIME STUDIES IN 2000*

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Abstract

Commissioned during the summer of 1999, RHIC is still a new machine, and its basic properties must be explored in detail. Among such investigations dynamic aperture and beam lifetime measurements are central. During the first year of operation an experimental record for the dynamic aperture and beam lifetime should be established under operational conditions. Further investigations should concentrate on intra-beam scattering, the effectiveness of local nonlinear interaction region correction, and persistent current effects.

1 INTRODUCTION

The two RHIC rings were commissioned during the summer of 1999. In the Blue ring a lifetime of about 45 min was achieved, while the lifetime in the Yellow ring was only a few thousand turns (less time was spent commissioning the Yellow ring). The next run calls for a systematic investigation of the effects that limit the dynamic aperture and the beam lifetime and thereby the achievable luminosity. Studies should concentrate on four objectives:

1. Measurement of the dynamic aperture and beam lifetime under operational conditions with varying parameters
2. Measurements of beam growth times due to intra-beam scattering
3. Test of the local nonlinear interaction region correction algorithm
4. Measurement of persistent current effects

Measurements of the dynamic aperture and the beam lifetime can be compared with calculations and simulations (see for example Ref. [1]). This will show how well certain aspects of the RHIC performance can be modeled. The collected data will provide a starting point for improvements.

Of special interest in these efforts is intra-beam scattering, expected to be the most important lifetime limiting effect in RHIC when operated with gold ions [2, 3]. Longitudinal growth times at injection are in the order of minutes.

RHIC uses a novel scheme for the local correction of the nonlinear magnetic errors in the interaction region triplets. A similar scheme will be used in the LHC. No operational experience for such a correction scheme exists and it is of great importance for RHIC and the LHC to establish a

Table 1: RHIC dipole kickers at injection energy. $\sigma_{x/y}$ denotes the transverse rms beam size.

Kicker	Strength range		Kick length
	$[\mu\text{rad}]$	$\sigma_{x/y}$	
Injection (ver)	300–1500	4.7–23.5	60 ns
Tune (hor)	0–11	0–0.2	90 ns
Tune (ver)	0–11	0–0.1	90 ns
Abort (hor)	250–2500	4.2–390	$> 12 \mu\text{s}$

working procedure. This topic is dealt with in detail in a separate paper [4].

Bench measurements indicate that time-dependent persistent current effects should only play a minor role in RHIC. A measurement with beam should confirm this.

2 EXPERIMENTAL TOOLS

In dynamic aperture measurements the available aperture will be filled with beam and the largest amplitudes at which particles can survive will be measured. A smooth closed orbit and retracted collimators are necessary to ensure that the dynamic aperture is not obstructed by the physical aperture.

In RHIC the vertical aperture will be filled with a single kick using the injection kickers. The horizontal aperture could be filled by the abort kicker, but safety concerns make an implementation of this scenario difficult (after the abort kicker is fired, it would not be available for some time thus making the magnets and other equipment vulnerable). Alternatively the horizontal and vertical aperture can be filled in many turns using the tune kickers. Tab. 1 summarizes the kick strengths of the available kickers at injection energy. At storage the strengths drop to one tenth of the stated values.

The dynamic aperture will be observed with an ionization profile monitor (IPM), which has been successfully tested last summer. The IPM is capable of recording profiles turn-by-turn, although such a high time resolution is not needed for dynamic aperture measurements. For reliable measurements the IPM has to be commissioned as an operational tool and its sensitivity must be determined experimentally. Fig. 1 shows a vertical turn-by-turn profile from the IPM with injection oscillations and the effect of coupling.

The beam lifetime will be measured with a beam current transformer. In Fig. 2 such a signal is shown. An application will fit the data and deliver the lifetime [6].

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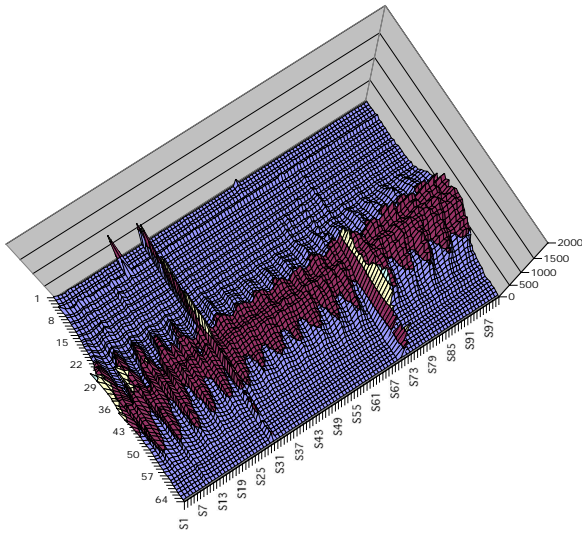


Figure 1: Vertical turn-by-turn profiles from an Ionization Profile Monitor, showing injection oscillations and the effect of coupling (7/27/99 15:00h) [5].

3 PARAMETER SCANS

The dynamic aperture and beam lifetime depend on numerous machine parameters. To find the best working point a systematic scan of the most important parameters can be done. These are

- Closed orbit
- Tunes
- Chromaticity
- Nonlinear detuning
- Local nonlinear interaction region correction
- Intensity

Measurements of nonlinear dynamic effects due to magnetic field errors are best done with protons or a gold beam with a small local phase space density (after a kick).

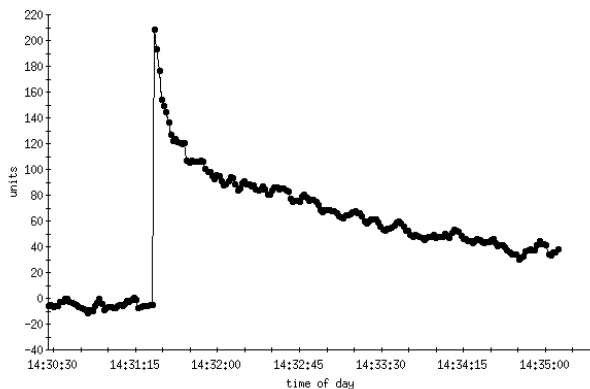


Figure 2: Total beam current versus time, without rf, showing a beam lifetime of about 3 minutes (7/27/99 14:36h).

4 INTRABEAM SCATTERING

Intra-beam scattering effects in gold beams are important at injection and storage. At injection, below transition, the longitudinal growth time for a gold beam is in the order of minutes [2, 3] and can be observed with a wall current monitor. The signal from this detector is shown in Fig. 3.

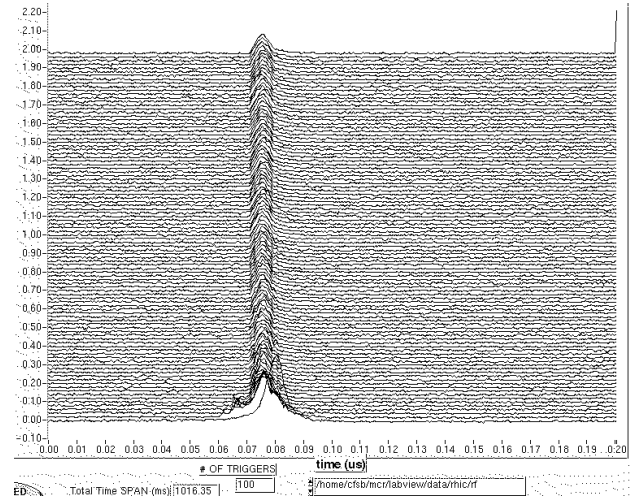


Figure 3: RF wall current monitor, showing captured beam surviving cleanly for the first second (7/19/99 07:20h).

At storage, above transition, the gold beam will grow in the longitudinal and both transverse dimensions. The longitudinal growth will be measured with the wall current monitor, while the IPM allows the observation of the transverse growth rate.

5 PERSISTENT CURRENT INVESTIGATIONS

Persistent current effects in RHIC are not as strong as in the HERA proton ring or in the LHC. RHIC's rigidity ratio between storage and injection energy is only 10, while it is 20 for HERA and the LHC.

During the commissioning run in 1999 some time dependent effects were observed. Although it was not possible to determine the cause of these effects, time-dependent persistent current effects might have played a role.

Once the main magnets of RHIC are ramped to the injection level, the persistent currents decay with time and change the sextupole component of the magnetic field. This leads to a slow change of the chromaticity. When the acceleration ramp starts the sextupoles will change back to their original value in a short time interval thereby changing the chromaticity rapidly. This effect is known as snap-back.

Bench measurements of the time dependent sextupole field in the dipoles have been made at 660A, somewhat above the injection level of 460A. Fig. 4 shows the measurements of 20 RHIC arc dipoles. Typically, the sextupole field changes by 1 unit in 5 minutes. We assume that the

persistent currents are approximately independent of the main current [7], and scale the measurements at 660A accordingly to lower values of the dipole current.

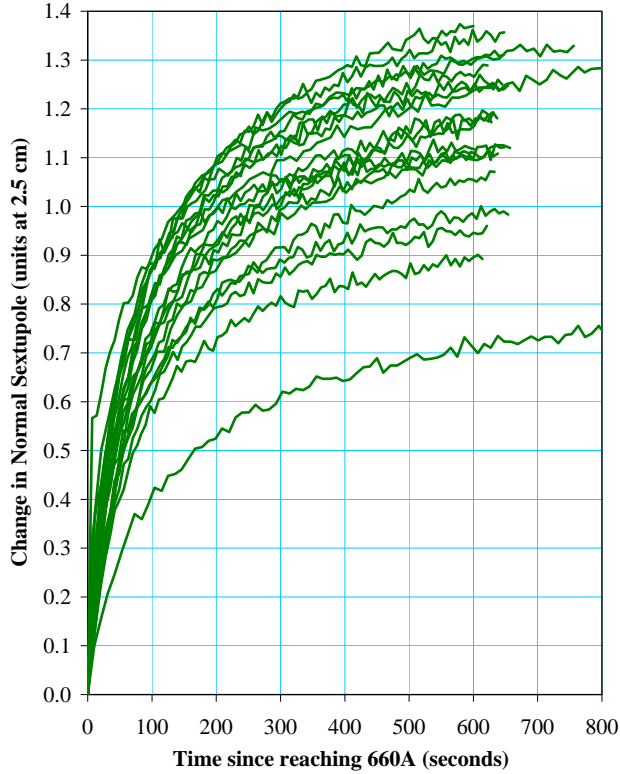


Figure 4: Time-dependent change of the sextupole coefficient in 20 RHIC dipoles, in units of 10^{-4} at a reference radius of 2.5cm [7].

Tab. 2 shows the change in horizontal chromaticity $\xi_x = \Delta Q_x / \Delta p/p$ for different injection energies after 5 minutes. With a momentum spread $\Delta p/p$ of about 0.001 off-momentum particles experience a change in the horizontal tune of up to 0.008 within 5 minutes when the relativistic γ is as low as 10.2.

Table 2: Change in the horizontal chromaticity due to persistent currents for different injection momenta after 5 minutes.

Relativistic γ	[1]	12.0	11.4	10.8	10.2
I_{dipole}	[A]	543	524	489	462
$\Delta \xi_x$ after 5min	[1]	-6.4	-6.7	-7.1	-7.5

The chromaticity can be measured at the injection level in 4 second intervals and monitored over several minutes. Chromaticity measurements should be in agreement with the results above that were derived from test bench measurements.

6 SUMMARY

Many phenomena and operational scenarios need to be explored for a good understanding of the RHIC machine per-

formance. Dynamic aperture and beam lifetime studies are central to these efforts.

The study of nonlinear effects that stem from magnetic field errors is best done with protons, since growth effects may be masked by intra-beam scattering effects when performed with gold. Gold, of course, should be used to study intra-beam scattering.

7 REFERENCES

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